

A Critical Review: Connecting Nature of Science and Argumentation

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ABSTRACT: The purpose of this critical review is to examine studies incorporating interconnectedness between Nature of Science (NOS) and Argumentation. This s in-depth critical review seeks to illuminate insights and direction of the linkage between these two eminent research fields in science education. It involves a computerized, web-based search to provide relevant studies consisting of conference papers, academic and peer-reviewed journals and well-known book chapters. The main selection criterion is the appropriateness of included products associated with the purpose of the review. Reputation of the research and recent impacts factors of higher-quality products are indicatives in specifying selection criteria. Additively, methodological aspect is considered to draw a more complete and holistic portrayal of the related studies regarding Argumentation and NOS. The presence of an Aptitude-Treatment Interaction (ATI) effect between NOS and argumentation instruction and, in addition to NOS understanding, gives necessary consideration to learners' Scientific Personal Epistemological Beliefs (SEBs) found to be prominent implications of the review. Other functional and methodological implications are also pointed out for further research related to the linkage between NOS and argumentation.

KEY WORDS: Argumentation, Nature of Science, Science Education, Scientific Epistemological Beliefs

INTRODUCTION

Today's world has been dominated by an inextricable enhancement of intellectualism favouring science and technology. It is also apparent that members of societies need to be scientifically and technologically literate if they are to possess a fruitful life (American Association for the Advancement of Science, [AAAS] 1989, 1990, 1993; BouJaoude, 2002; National Research Council [NRC] 1996).

To our knowledge, as recommended by most jurisdictions (AAAS, 1989, 1993; Michaels, Shouse, & Schweingruber, 2008; Millar & Osborne, 1998; NRC, 1996), possessing a meaningful comprehension toward 'Nature of Science' (NOS) is a crucial component of scientific literacy. Moreover,

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as other camps of research (e.g. Driver, Newton & Osborne, 2000, Duschl & Osborne, 2002, Kuhn, 1993, Tytler, 2007; Wan & Wong, 2013) have advised ‘Engaging in Argumentation’ is a life-sustaining demand to civilize individuals as scientifically literate members of society to deal with and make critical decision regarding everyday issues of science and life itself. Therefore, as a logical inference, these two rising fields within science education may be supposed as ‘taken-for-granted’ in referring to a learner’s level of scientific literacy. In a similar vein, reciprocal productive interactions between NOS comprehension and being engaged in argumentation have already been acknowledged in a non-septic sense. Nevertheless, the question arises as to whether it is actually reasonable to accept an organic link between NOS understanding and generating better science arguments

An initial piece of evidence come from the early studies of the philosophy of science. Khishfe (2012b) argues that a conceptual or operational link between NOS and argumentation is neither obvious nor straightforward. On the one hand, it goes without saying that scientists often engage in constructing arguments as a matter of course; this is part and parcel of their practices (AAAS, 1993; Lederman, 1992; Matthews, 1994, 1998; NRC, 1996). Thus, it is expected that all *good* scientists are capable of making better arguments. However, on the other hand as Kuhn (1962) convincingly argues and demonstrates, it is not the case that all good scientists understand the epistemological underpinning of their routine practices. This claim is supported by empirical evidence that goes back to the study conducted by Kimball in the late 1960s where he compares the NOS understanding of science teachers, scientists, and philosophy of science students. The latter group out-performed the former two in their NOS scores; while scientists and science teachers did not differ much in their NOS scores (Kimball, 1967). Medawar (1969; 1973) was among the first denoting that ‘scientists often *do not* articulate informed views concerning philosophical underpinnings of their disciplines. All this is to say that scientists can put forward great arguments without necessarily having an informed NOS understanding. But this argument may also be conceived as presumably contradictory.

The second reason for this potential combination (NOS and argumentation) is due to the instructional issues related to the teaching and learning of *well-defined* NOS aspects (e.g., McDonald & McRobbie, 2012). To be clear, even though implicit and explicit NOS instruction serve as effective teacher pedagogy in enhancing learners’ NOS comprehension, there are still troublesome deficiencies to achieving the desired learning outcomes (Abd-El-Khalick & Lederman, 2000b, McComas, 2002). At first, Lederman (1992) supported this by announcing that the development of learners’ perspectives regarding aspects of NOS is substantially challenging and compelling. Moreover, as Abd-El-Khalick and Akerson (2004)

articulated, explicit NOS instruction is somehow insufficient to scaffold learners' comprehension concerning aspects of NOS. However, in response to earlier mentioned issues within NOS instruction, survival mechanisms have been raised through the efforts of science educators, particularly operational argumentation as a powerful facilitator enabling teaching and learning the aspects of NOS (e.g., McDonald & McRobbie, 2012).

There are other reasons to consider the integration of studies pertinent to NOS and argumentation. There are unclear and dubious views about the authentic linkage between NOS and argumentation. Moreover, it is still disputable whether or not NOS understanding has [positive] effects on argumentation skills of students or whether argumentation acts on students' understanding regarding aspects of NOS (e.g., Khishfe, 2013).

Based on the above-stated issues, the aim is to synthesize several studies admitting argumentation and NOS to reveal whether there is an intersection between them NOS. The studies included are sorted according to reciprocal effect of NOS and argumentation on each other. Thus, as McDonald (2010) proposes, categorization can be either the 'influence of NOS views on argumentation' or the 'influence of argumentation on NOS views'. In addition to these categorizations, studies are also sorted as studies 'conducted in scientific contexts', 'socio-scientific contexts', 'both in scientific and socio-scientific contexts', and 'historical contexts'. Such an elaborated review of diverse categorizations is revealed within the frame of a doctoral dissertation (McDonald, 2008).

The potential outcomes of the study will be informative pertaining to further research exploring the relationship between NOS and argumentation. This is conducted with respect to how some aspects of NOS understanding influence argumentation, or how argumentation contributes to the comprehension of more analytic aspects of NOS (e.g., tentative NOS). To go further, the study does not only illustrate the interconnectedness of two featured fields, it incorporates methodological suggestions to detect deficiencies or recommend alternative research methods regarding the linkage.

METHODS

The study is neither a content analysis nor a meta-analysis; such approaches are beyond the scope of this review. This study simply provides a review to elucidate the interconnectedness of NOS and argumentation.

In the course of the literature search, conducted in 2014, I identified several studies respecting NOS and argumentation. A computerized reference database [ERIC and SSCI] was used to dig for potentially *appropriate studies* that those were published after 2000. The searched was conducted using specified keywords such as '*nature of science*', '*argumentation*', and '*science education*' and other synonyms and related

terms. Types of primary and secondary references were limited to ‘Academic Journals’, ‘Conference Papers’ and ‘Book Chapters’. Principally, academic Journals were selected according to their higher impact factors. These were Science Education (SE, impact factor: 2.382, as stated in 2013), International Journal of Science Education (IJSE, impact factor: 1.340, as stated in 2013), Journal of Research in Science Teaching (JRST, impact factor: 2.552, as stated in 2013), Learning and Instruction (L&I, impact factor: 3.621, 5-year impact factor) and Cognition and Instruction (C&I, impact factor: 2.379, 5-year impact factor). Moreover, conference papers were selected from those by the National Association for Research in Science Teaching (NARST) and the American Educational Research Association (AERA).

Table 1 **Information about reviewed published studies**

Identification of source	Selection criteria	Frequency
International Journal of Science Education	Higher impact factor	6
Science Education	Higher impact factor	2
Journal of Research in Science Teaching	Higher impact factor	3
Learning and Instruction	Higher impact factor	1
Cognition and Instruction	Higher impact factor	1
Handbook Chapters	Collective book	1
National Association for Research in Science Teaching Conferences	Important international science education conference	1
American Educational Research Association Conferences	Important international educational conference	1

Furthermore, a well-known and comprehensive book that incorporates collective studies in relation with ‘Argumentation in Science Education’ was searched to find any clues concerning the linkage. The final outcome was a total of 16 studies with superior relevancy. The frequencies of the selected published pieces of works were as shown in Table 1. For this review, intersections of argumentation and NOS are displayed as studies conducted in scientific and socio-scientific contexts. Studies, then, were also expressed as ‘NOS views influencing argumentation’ and ‘argumentation influencing NOS views’.

REVIEW OF RELEVANT LITERATURE

Studies on integration of NOS and argumentation

Seven of 16 studies were conducted in scientific contexts whereas nine of them were implemented in socio-scientific contexts, although some studies do not reflect a complete involvement of both NOS and argumentation. Some reviewed studies incorporated *epistemological orientations or scientific epistemological beliefs of learners* (e.g., Marra & Palmer, 2005) instead of NOS and *decision-making of learners* instead of argumentation. However, epistemological orientations or scientific epistemological beliefs of learners were inherently related with NOS aspects (Lederman, 1992) while decision-making is a unique form of informal reasoning which incorporates argumentative discourse (e.g., Means & Voss, 1999). Therefore, these types of studies were also taken as representative and relevant to the purposes of the review.

The selected studies are described, based on the specifications to clarify the focalized differences among them:

- purpose of the study,
- context(s) of study (i.e., scientific or socio-scientific or either of them),
- participants or sample of the study,
- whether there was an explicit/implicit instruction of NOS,
- whether there was an explicit/implicit instruction argumentation,
- the direction of influence (i.e., NOS influences engagement in argumentation)

First, studies conducted in scientific contexts are considered and then, in turn; the studies conducted in socio-scientific contexts are discussed.

Studies conducted within a scientific perspective

In this section, seven studies are considered 'scientific context'. In addition, methodological suggestions referring to research design approaches are included.

The first attempt comes from Yerrick (2000). Yerrick studied five learners who had lower achievement. The students were required to engage in activities to yield justified argumentations, establish experimental designs and interrogate obtained data in the form of evidence. In open inquiry-based sessions, argumentative skills and strategies were explicitly taught to the five subjects and there was no explicit NOS instruction. Analysis of data was based on the Toulmin Argumentation Model (Toulmin, 2003) and provided evidence that five low-achieving students improved their understanding regarding tentative NOS, utilization of

scientific evidence and interrogation practices of scientific/epistemic authority. However, as investigating the linkage between NOS and argumentation was not the primary purpose of this study, it was taken as only an indirect indication of linkage.

The second study, conducted by Bell and Linn (2000), had an intentional research design to identify the linkage between NOS and argumentation. The rationale for the study was to determine whether NOS aspects were evident in 172 middle school students' arguments. Explicit argumentation instruction was furnished through a software program, but there was no explicit NOS instruction. Informed users of aspects of NOS enabled frequently the bringing forth of justifications in advocating their views. Moreover, the authors quoted evidence (post-test results of participants' understanding toward NOS aspects) that the explicit teaching of argumentative strategies resulted in heightened NOS comprehension.

Over five years, Sandoval and Millwood (2005) explored the influence of 87 high school biology students' epistemological understanding on their argumentation. The aim of the study was to testify whether epistemological views explicate argumentation quality. There was no explicit NOS instruction nor and assessment of pre/post- NOS understanding of participants. The results of the study, showed that even in the presence of scaffolding argumentation using a software tool, students still had incompetence in defending their arguments and in coordinating knowledge claims accompanying evidence.

In their study, Kenyon and Reiser (2006) claimed that 64 middle school students could elicit their NOS understanding if they were employed in inquiry-based implementations that were intentionally oriented to the learners' epistemological views. Explicit argumentation instruction was used to acquaint students. The authors established an instructional design to create a felt need by students to express their epistemological views while undertaking argumentation. Locating a context for students to apply their epistemological views in the course of engaging in argumentations, as the authors asserted, positively sustained the NOS understanding of participants.

Sandoval and Millwood (2007) investigated 7th graders' (N=33) tendencies toward warranting their knowledge claims. They explicitly explored whether students' progressive argumentative strategies affect their NOS comprehension. The students' initial NOS understanding was evaluated and found at a 'naïve' levels. There was no explicit teaching of argumentation; however, engagement of students in argumentative processes was supported through software tools. Their findings demonstrated that the learners' epistemological views positively impacted on their strategies with respect to engaging in argumentation.

Nussbaum, Sinatra and Poliquin (2008) sought whether students' epistemological orientations and supported argumentation had an effect on

their argumentation quality. At the beginning of the study, participants were sorted according to their epistemological orientations as ‘absolutists’, ‘multiplists’ and ‘evaluativists’. Students with absolutists and evaluativists epistemological orientations engaged in argumentation more frequently and profitably compared to students with multiplists epistemological orientation. Students with evaluativists epistemological orientation were capable of engaging in argumentation more fruitfully than the other two groups of students and demonstrated less inconsistency within their reasoning. General findings from the study showed that the participants’ existing epistemological orientations had an influence on their argumentation quality. However, there were inconsistencies among the epistemological orientations since they were constructed by taking into consideration a *hierarchy* (Kuhn, 1992).

In addition to the six studies mentioned, a more recent study by McDonald (2010), explored the effect of explicit instruction of NOS and argumentation on NOS understanding of five pre-service primary teachers. The pre-service teachers were engaged in argumentation both in a scientific and socio-scientific sense. She found, with the aid of a further and critical analysis, there might be three *mediator* variables shedding light on the interaction between NOS and argumentation. These are ‘*contextual factors*’ (e.g., contexts of discussion topic as scientific or socio-scientific, background knowledge, inadequate oral argumentation skills, and nature of the discussion group), ‘*personal factors*’ (e.g., previous knowledge, lack of an appreciation of argumentative discourse), and ‘*task-specific factors*’ (e.g. presence/absence of epistemological probes, level of supported argumentation). In order to *remedy* participants’ NOS understanding and engagement in argumentation, outcomes indicated that explicit instruction on both NOS and argumentation were essentially needed.

To conclude this section, assertions in the form of critics are posed emanating from the seven studies.

#Assertion I: *Engagement in argumentation and yielding higher quality arguments are not identical entities.*

Studies locating findings in, NOS comprehension show this has influence *either* on their ‘argument quality’ *or* ‘engagement in argumentation’. However, ‘*engagement in argumentation*’ and ‘*articulating a higher quality argument*’ are not identical entities. Learners may engage in argumentation frequently, however, it does not guarantee putting forward higher quality arguments (Means & Voss, 1996). It is therefore uncertain whether individuals with informed NOS views or higher epistemological understandings actually construct well-formulated argumentations or they draw on their knowledge with respect to aspects of NOS while engaging in argumentation in a confident posture.

#Assertion II: *Supported argumentation and explicit teaching of argumentation should not be used interchangeably.*

It is not a straightforward task to sort out the influence of argumentation on individuals' NOS views in the aforesaid studies in which either 'supported argumentation' or 'explicit teaching of argumentation' are materialised. Even though the researchers comparatively define the scope of the supported argumentation and explicit teaching of argumentation, to our knowledge, these entities are qualitatively distinctive entities. To explain, in terms of supported argumentation, several specifically designed software packets are utilized to scaffold students' argumentations (e.g., Bell & Linn 2000; Kelly & Takao 2002; Zohar & Nemet 2002). On the other hand, explicit teaching of argumentation consists of *deliberative* instruction of pieces of information about argumentation, argumentative skills and strategies. To be clearer, in the course of explicit teaching of argumentation, basic argumentative skills such as taking a position to a knowledge claim, generating counter-arguments and rebuttals need to be introduced in different contexts, and the importance of such skills within the context of argumentative discourse needs to be emphasized (Erduran, Simon & Osborne 2006; Jimenez-Aleixandre & Erduran 2007). Thus, the inference indicating supported argumentation scaffolds students' both argumentation skills and NOS understanding are dubious.

#Assertion III: *The predictor and criterion variables, as NOS understanding and argumentation, are blurred.*

There is a clear contradiction within the studies presented in this section. The studies provide evidence that even though there is no explicit NOS instruction, only in the presence of explicit argumentation instruction or support, are an individual's argumentation quality and NOS views improved to a certain level. However, to our knowledge, existing NOS research have promoted the fact that it is hardly likely to enhance an individual's NOS views *in the absence of explicit NOS instruction* (e.g., Akerson, Abd-El Khalick & Lederman, 2000; Abd-El Khalick & Lederman 2000b; Khishfe & Abd-El Khalick 2002; Schwartz & Lederman, 2002). Also, there are studies indicating *both NOS instruction and explicit teaching of argumentation* improve both NOS views of individuals and argumentation quality (e.g., McDonald, 2010; Ogunniyi, 2006). It is therefore thought-provoking as to which variable is the predictor, or criterion. Thus the situation is unclear as to whether NOS understanding *predicts* argument quality as the *criterion* variable or the reverse. Thus the anticipated question becomes 'are there conditions in which NOS understanding and argumentation execute as either predictor or criterion variables?' Therefore, as a suggestion, there needs to be diverse research

designed to solve this critical issue. For instance, within well-controlled true/quasi-experimental designs, one group can be given both explicit NOS and argumentation instruction and the other group can be introduced only to explicit teaching of argumentation or only explicit teaching of NOS.

#Assertion IV: *There are insights of Aptitude-Treatment Interaction (ATI) approach that explore the linkage.*

McDonald (2010) revealed the fact that additional components coined as ‘contextual’, ‘task-specific’ and ‘personal’ when making plausible connections between NOS understanding and argumentation. Furthermore, McDonald, *consciously or unconsciously*, executed her study under the presumable influences of an ATI effect. This is because, she substituted some ‘[E]pistemological probes in the form of written or verbal prompts’ within the frame of task-specific effects in order to scaffold learners to engage in socio-scientific argumentation and to point out the necessity of articulating alternative data and explanations. However, no evidence was given as to whether the aforesaid *epistemological probes* were functionalized in a *desired* manner favouring both low-high achievers or those less-more skilled [e.g., oral argumentative skills] learners. In this context, an ATI research approach should be adopted. To clarify, ATI would stand for ‘permitting the investigation of how *individual differences modify treatment effects*.’ (Koran & Koran, 1984, p. 793; italics added). In other words, an ATI research could easily permit the interrogation of how, in the case of McDonald, task-specific, contextual and [inherent] personal differences radically altered the pre-specified and anticipated treatment effects (e.g., explicit teaching of NOS and/or argumentation). To advocate, as McDonald acclaimed, for instance in terms of contextual factors, due to *a lack of provision of specific content knowledge*, students were more blocked to engage in scientific argumentation compared to socio-scientific argumentation processes in which less information was *likely* needed. If this was the case, a remedial type of ATI approach should be taken into consideration. Once again, as Koran and Koran declared;

‘[I]n the remedial model, learning deficiencies are believed to be a result of specific *knowledge*, skills, or abilities which are *lacking*. Treatments are therefore designed to remedy this deficit. In its simplest form such a treatment consists of a remedial loop designed to remedy specific gaps in the *students’ initial knowledge* (Koran & Koran, 1984, p. 801; italics added).’

If the presence of ATI is explicated for earlier mentioned research through concrete empirical evidence, more enriched, or fertilized, scientific content concerning required task structure could be supplied for learners, scaffolding their genuine engagement in argumentation and it would be a

remedial model for *less knowledgeable* students (e.g., Fleishman, 1972; Salamon, 1972). To advocate, the basic principle of remedial model was to change learner's capabilities rather than treatment designs that those were either *compensating for* their lack or capitalizing on alternative abilities (Koran & Koran 1984). In this way, more analytical and invisible insights of the expected treatment effects could be revealed in a more sensible and detailed perspective.

Studies conducted within a socio-scientific perspective

The first mentioned study was conducted by Zeidler, Walker, Ackett and Simmons (2002) by presenting participants with moral dilemmas. The subjects of the study consisted of a combination of 82 individuals from grade 9th-10th high school students to pre-service elementary teachers. There was no explicit teaching of NOS and argumentation. Therefore, the purpose of the study was to detect the NOS views of participants in responding to socio-scientific issues (SSIs). Particularly, two aspects of the NOS were revealed in negotiations of subjects as 'social-cultural' and 'empirical' aspects of NOS. The authors of the study advocated the idea that by confronting subjects with ill-structured scenarios and engaging them in-depth interrogations of rhetorical evidence and warrants this was an effective way to uncover their NOS acquisitions. However, there was no intentional assessment of NOS views of subjects thus reducing the reliability and validity of the study's inferences.

One year later, Bell and Lederman (2003) researched the influence of NOS views on decision-making of individuals regarding socio-scientific issues. Participants of the study were 21 university professors and research scientists. There was no deliberate NOS and argumentation instruction. A pre-test was administered to assess the participants NOS views; prior to decision-making applications and a decision-making questionnaire was given to participants to observe their decision-making patterns. An initial finding of the study indicated that NOS understanding was not a prominent predictor of participants' decision-making patterns. Personal, social, political and moral insights of introduced issues were considered instead of inferring from *scientific evidence* within the decision-making by participants.

Another study was conducted by Sadler, Chambers and Zeidler (2004) challenging the findings of the study by Bell and Lederman (2003). The aim of the study was very similar to that of the Bell and Lederman study, but Sadler et al. (2004) selected global warming as the socio-scientific issue. Moreover, they also investigated 84 high school biology students' evidence concerning their 'persuasiveness' and 'scientificness'. There was no explicit teaching of NOS and argumentation or evaluation of the quality of students' argumentation. Contrary to findings by Bell and Lederman, they provided evidence that students reflected on three NOS aspects: (i)

tentative, (ii) social and (iii) empirical, during socio-scientific negotiations. According to the findings by Sadler et al., particularly the tenet *scientific knowledge is socially constructed*, influenced students' argumentation substantially with regard to persuasiveness and scientificness.

Walker and Zeidler (2004) conducted another study investigating NOS and argumentation linkage. The study's main purpose was to examine whether a web-supported instructional tool scaffolding participants' views on NOS informed their decision-making processes. There was explicit teaching of NOS and supported argumentation. However; there was no explicit teaching of argumentation. Participants were 36 students enrolled in a high school science class. Participants' NOS views were pre-evaluated, yet there was no attempt to measure their argumentative skills prior to the beginning of the study. The results showed that NOS views were not explicitly exhibited in students' arguments in the form of decision-making patterns. In addition, there were several insufficiencies within the students' arguments so that they were not able to actualize evidence-based reasoning.

To add a different point of view, Mason and Scirica (2006) investigated how students' argumentation skills could be estimated through their epistemological understanding. This study might be considered as more powerful to investigate the contribution of an overall epistemological understanding of 62, 8th graders on their argumentations while controlling 'knowledge of content' and 'interest to topic'. Students were engaged in argumentations through socio-scientific issues. Argumentative skills were identified as (i) generating arguments, (ii) counter-arguments and (iii) rebuttals. Also, participants were divided according to their epistemological orientations as either multiplists (74.2%), or evaluativists (25.8%). At first, this study obtained evidence that evaluativists participants had the ability to demonstrate the three argumentation skills more accurately compared to students who adopted multiplists epistemological orientation. This conclusion was valid both for scenarios (changing *context*) and knowledge of content (varying degrees). In general, the study supported the idea that adopting higher-epistemological orientation estimated argumentation quality. In other words, as a clear inference, incremental epistemological understanding positively and fruitfully influenced the argumentation quality.

A more recent study investigating the possible interaction between NOS and argumentation was carried out by Wu and Tsai (2011) who investigated whether there was a strong relationship between students' scientific epistemological beliefs (SEBs; *development*; a dimension of scientific beliefs related to beliefs about the nature of scientific knowledge and *justification*; a dimension of scientific beliefs related to the beliefs on the nature of knowing science, p. 396) and their informal reasoning quality. In this study 68, 10th graders' SEBs and informal reasoning qualities were assessed prior to the research. The results of the study supported the idea

that students' SEBs toward 'development' and 'justification' were considerably connected to locating rebuttals as the premier indicator of higher-quality informal reasoning and argumentation.

To sum, there are two prominent assertions from the general findings of these six studies.

#Assertion I: *Mixed results of the studies may be illusive and further studies are needed.*

The four former studies pointed to evidence of mixed results about the linkage between NOS and argumentation; some studies announced an interaction (e.g., Sadler et. al 2004) and others did not (e.g., Bell & Lederman, 2003). However, other studies strengthen the idea that aspects of NOS could be taught more relevantly and fruitfully by means of embedding them into socio-scientific issues, and hence in turn, socio-scientific argumentation (e.g., Bently & Fleury, 1998; Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Khisfe & Lederman, 2006; Sadler, Chambers & Zeidler, 2002; Simmoneaux, 2008). Therefore, the mixed results of the studies might be illusive and the need for further studies were needed.

#Assertion II: *NOS understanding and SEBs are not identical, but may work collectively.*

The two latter studies located in this section (Mason & Scirica, 2006; Wu & Tsai, 2011), contrary to four former studies, approached the fact that there was a true consistency between informal reasoning (argumentation) and learners' SEBs. In other words, when epistemological beliefs about scientific epistemology were involved in studies, *NOS and argumentation linkage became clearer and apparent*. To explain, as also requested by Wu and Tsai (2011), the illusive condition originated from the fact that researchers had established an unintentional *blurred genre* by engaging views about NOS in SEBs of learners. However, the reality showed that they were distinctive components. To our knowledge, NOS, generally speaking, referred to inherent assumptions, characteristics and values of scientific knowledge (Lederman, 1992; Tsai & Lui, 2005). Conversely, SEBs were the beliefs about the nature of scientific knowledge and the nature of knowing (Kuhn, 1999, 2000). More importantly, SEBs were not directly related to philosophies of science since these were *personal epistemologies* (Hofer & Pintrich, 1997). Accordingly, NOS generally dealt with social and cultural insights and the process of production of scientific knowledge, while learners' SEBs was more related with why we know, how we know, and to what extent we know, the validation and justification strategies of knowledge. Also, from a different perspective, learners' SEBs might be thought of as comparatively associating to their informal

reasoning and decision-making processes, particularly regarding SSIs in which those processes, to our knowledge, might apply to their personal beliefs as in the form of emotional reasoning (Zeidler, Walker, Ackett & Simmons, 2002). Therefore, in addition to different aspects of NOS, individuals' SEBs should also be contributively explanatory and exploratory in empowering the linkage between NOS understanding and argumentation. This assertion, implicitly or explicitly, had also been supported by other researchers (Kuhn, 1991; Mason & Boscolo, 2004; Mason & Scirica, 2006).

A new look at the linkage between NOS understanding and argumentation

In 2012-13, Khishfe examined this linkage in a more analytical sense by conducting fine-grained analyses. Initially, Khishfe (2012a) investigated the relationship between NOS understanding and argumentation skills in terms of the role of counter-argument and effect of contextual factors. In this study, participants were 219, grade 11th students, who were engaged in socio-scientific argumentation about two different issues - genetically modified foods and water fluoridation. There were no explicit NOS and argumentation instruction. She considered three pre-defined NOS aspects; *subjective, tentative and empirical NOS*, and associated them with three argument components - *argument, counter-argument and rebuttal*. One key finding of the study was that establishing counter-arguments made more connections to the three NOS aspects compared to rebuttals and arguments. Additionally, this study revealed that participants' socio-scientific argumentations were affected by contextual factors. To illustrate this, students located more well-formulated arguments within water fluoridation than genetically modified foods due to sub-factors. Contextual factors were exposure to and familiarity with the discussed controversial issue that stood for more familiarity and local exposure to the discussion topic (e.g., water fluoridation) which might cause students to articulate more advanced arguments, counter-arguments and rebuttals.

In the second study, Khishfe (2012b), even though it is not directly related to an individual's argumentation, investigated the relationship between NOS instruction and students' decision-making within a controversial issue such as genetically modified foods. Participants of the study were 22, 9th graders. She created four groups to test the hypotheses that those in the comparison group received instruction regarding genetic engineering, how to formulate arguments and make decisions on genetically modified organisms. On the other hand, in the treatment group, instruction was conducted pertinent to genetic engineering and how to apply NOS aspects, but also they formulate arguments and make decisions in relation to genetically modified foods. The prominent finding showed that explicit NOS instruction improved the students' understanding of NOS.

Secondly, there were no significant differences in decision-making of students although they were previously exposed to explicit NOS instruction.

The third study by Khishfe (2013) included two featured purposes:

- 1) Investigating the influence of explicit argumentation and NOS instruction on both NOS understanding and argumentation skills of students,
- 2) Identifying whether students transfer their acquisitions obtained from explicit instruction of NOS and argumentation to other contexts that may be similar to or different from previous introduced contexts.

Participants were 121, 7th grade students. There were two treatment groups namely Treatment I (*explicit teaching of NOS and argumentation*) and Treatment II (*explicit NOS with no explicit instruction of argumentation*) implemented in two different schools. In both schools, Treatment I and Treatment II were conducted to see the effect of both explicit NOS and argumentation instruction. The findings of the study indicated that explicit argumentation instruction as a part of the implementation was primarily in action. Moreover, explicit teaching of NOS to students, worked well in enriching students' understanding toward some aspects of NOS and this was valid for both familiar and unfamiliar contexts, with respect to transferability of the understanding of focused NOS aspects. The combination of explicit instruction as NOS and argumentation had no significant effects on improving students' NOS understanding. However, students engaged in Treatment I could build connections between NOS aspects in their argumentations. Also, the explicit instruction of NOS and argumentation skills contributed to the transferability of those skills and understanding from one context to another.

To summarise, thanks to Khishfe's three studies, there are substantially worthy implications. First, contextual factors (e.g., exposure and familiarity, prior content knowledge and personal relevance) are found as important for understanding in terms of the linkage between NOS understanding and argumentation. As another contribution, personal relevance of argued issues becomes prominent. As a methodological suggestion, in this type of studies, in which contextual factors change the expected linkage between NOS understanding and argumentation, some need to be designedly to include *controlled factors* as in the study by Mason and Scirica (2006). For instance, this can apply in the case of knowledge of content in order to *verify executed independent variables and not to deteriorate the linkage between NOS and argumentation*. It is therefore plausible to recognise Shaver's (1983) ideas regarding the 'verification of independent variables'. In addition, if it is not possible to

control for extraneous variables that effect the linkage, *more individualized tasks* may be structured as particularly concerning personal relevance of the controversial issues.

Moreover, even though a substantial relationship should be anticipated between the explicit NOS instruction and decision-makings of students, one of Khishfe's studies (Khishfe, 2012b) did not indicate that interaction completely. There were meaningful explanations of this relatively contradictory result.

To illustrate, at first, the linkage between NOS understanding and decision-making has not been examined frequently. There are a few research studies exploring this interaction (e.g., Eggert & Bogeholz, 2010; Bell & Lederman, 2003). More importantly, even though several science educators support the idea that informed decision-making is an indicator of scientific literacy (Bodmer, 1986; Ramsey, 1993; Zoller, 1987) and several researchers have trialled and assessed instructional materials to scaffold decision-making of students (Jager & van der Loo, 1990; Aikenhead, 1991; Kortland, 1992), very few studies have questioned the structure and the nature of decision-making of students (Aikenhead, 1994). Thus, as a logical inference, there is a felt need for more studies both investigating the nature of decision-making of individuals and in turn, the vistas of decision-making of learners that is supported by explicit NOS instruction.

Finally, Khishfe (2013) indicates the fact that within a more rigorous research design, explicit teaching of both argumentation and NOS are the first necessities to provide evidence for advancement in an understanding of NOS. In other words, in the absence of explicit teaching of NOS and argumentation, it is hard to observe the enhancement of NOS views and argumentation skills. However, even though a combination of explicit instruction of NOS and argumentation have enriched students' NOS views in some aspects, *the interaction is still unclear to reliably prove a strong connection between NOS and argumentation*. Further replication studies are needed.

RESULTS

This critical review aimed at attesting the linkage between NOS understanding and argumentation. After reviewing and synthesizing several studies in a fine-grained manner, several prominent suggestions come are put forward for a more effective NOS instruction through true argumentation.

First, as mentioned earlier, studies exploring linkage between NOS understanding and argumentation has been pervasively based on either scientific, or socio-scientific, content and contexts. In addition to this, students may be engaged in argumentation to comprehend the aspects of NOS. For instance, students may be engaged in argumentation regarding

NOS, myths about NOS, validation of knowledge claims, science as a way of knowing and so forth. Putting it differently, under the effect of explicit instruction of argumentation, students may be immersed in argumentation regarding the conceptualizing of NOS and epistemology.

Second, obviously more rigorous ‘experimentally designed studies’ are required for explaining the linkage between NOS understanding and argumentation. Besides that, conducted by Khishfe (2013), this research area is still in need of more to obtain concrete empirical evidences to support the idea that argumentation is an instrumentally, operationally and conceptually appropriate cognitive apparatus to improve NOS understanding of learners.

Third, as an alternative research approach, Aptitude-Treatment Interaction (ATI) Research should be considered to deliver the main value to individual differences that manifest themselves, for instance, in terms of task-specific, personal and contextual factors. These can be thought of as the moderating elements influencing the interaction of NOS understanding and argumentation (McDonald, 2010; Khishfe, 2012a).

Fourth, studies conducted in socio-scientific contexts generate mixed results with respect to interaction between NOS understanding and argumentation in the presence of evidence that those represent socio-scientific issues can be utilized as fruitful contexts to both distinguish and improve learners’ NOS views. Obviously, more research is needed to enlighten the scope of the studies in socio-scientific contexts with the aid of gathering more qualitative data in addition to quantitative data through mixed-methods designs.

Finally and more importantly, inclusion of epistemological orientations (Mason & Scirica, 2006; Nussbaum, Sinatra & Poliquin, 2008) and scientific epistemological beliefs of learners (Wu & Tsai, 2011) into studies investigating the linkage between NOS understanding and argumentation might be more elucidative. In this critical review, it is well understood that scientific epistemological beliefs of learners can be exploited as mediating and moderating constituents in manifesting the linkage between NOS understanding and argumentation.

In conclusion, it is impossible to disclaim interactions between NOS and argumentation to enhance both learners’ argumentative discursive skills and NOS comprehension. However, it needs to be acknowledged that this interaction has to be supported with more research-based data

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